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THE EFFECT OF CUTTING CONDITIONS ON FRICTION COEFFICIENTS AND CUTTING POWER IN THE FLY-HOBBING PROCESS USING NANOLUBRIANTS

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ABSTRACT

The friction in the gear hobbing process has a great effect on the tool wear, cutting force, cutting temperature and the quality of the machined gears. Applying nano lubriants using normal oil added Al_2O_3 nanoparticles may reduce the friction in the gear hobbing, because the nearly spherical Al_2O_3 nanoparticles easily enter into the contact area friction between the chip and tool. However, Gear hobbing is the complex machining process using the tool hob and there are many teeth joining together in the machining process. So, an experimental model using the single tool on a horizontal milling machine was set up so that the size of the chip produced was the same as the largest cutting chips produced during the hobbing process. This study focused on the effect of the cutting conditions on the friction coefficient and the cutting power through the value and ratio (S/N) by the Taguchi's method. The results indicated that nanoparticles size and nanoparticles concentration were the most significant parameters that influenced the friction ratio in the fly hobbing process. The friction ratio is the smallest value to the nanoparticle size 20nm and 0.5% Al_2O_3 nanoparticles. Furthermore, using the nanofluid can reduce the cutting power in the fly hobbing process.

KEYWORDS: Friction, Cutting Power, Nanofluid, Al_2O_3, Taguchi, Hobbing, Gear & Optimization

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Original Article

1. INTRODUCTION

Gear hobbing is one of the most complicated metal cutting processes, the rotary motion of workpiece depending on the rotary of tool hob and many teeth joining in the machining process. So, the friction, high dynamic force and heat generated in the cutting process are the main causes to reduce the flank wear of tool, the accuracy of gears and the quality surface in the gear hobbing process. In recent years, in order to reduce the friction and enhance the metal cutting performance, the cutting fluid has been added to the nanoparticles. In there, the cutting oil mixed aluminum nanoparticles have been used by many researchers, because they have many advantages as a thermal resistance, spherical shape, great abrasion resistance and a high specific heat [1,2]. In recent studies, Mostafa Hadi and Reza Atefi (2011) revealed that the quality of surface can be improved when applying the cutting fluids mixed aluminum oxide nanoparticles in machining AISI D3 steel [1]. A. N. M Khalil (2015) studied the influence of the nanolubricant added Al_2O_3 nanoparticles to improve tool life in the turning process of AISI 1050. The study found the optimal parameters for the tool life in the turning process using the nanofluid [2]. The influences of the cutting fluid mixed Al_2O_3 nanoparticles on the quality of the surface and cutting force, and generation chip was studied by Songmei Yuan et al. The results were shown that the performance of the cutting process using nanofluids was better than the cutting process using the normal cutting fluid [3]. Guotao Liu et al studied the influence of nanofluid on the cutting force, temperature, energy and surface roughness in the grinding process [4]. Meshkat and S. Khalilpourazary compared the quality surface and the flank wears of the hobbing process using nanofluids add 0.2% nanoparticles 80 nm with the process using normal oil [5]. The

results shown that the surface roughness and the tool wear using nanolubricants were smaller than using normal oil. Further, The hobbing process uses the expensive tool hob and has many complicated generated motions. Hence, it is very difficult and costly to determine the friction ratio, dynamic force and other parameters in the machining gear process. So, A fly hobbing process using the single tool was proposed to study about the fundamental problems of the hobbing by many authors as J. Hoffmeiter (1970), Yoji Umezaki (2012), S. Stein (2012) [6-8]. However, the effect of Al_2O_3 nanoparticle on the friction coefficient and the cutting power in the fly hobbing process has not been studied yet. The present paper focuses on studying the effect of the cutting conditions on the friction coefficient and the cutting power in the hobbing process by using the fly hobbing modern. The optimization of the cutting conditions in the fly hobbing process with nanofluids is studied by using a Taguchi experiment model.

2. MATERIALS AND EXPERIMENTAL METHODS

2.1 Materials

The actual hobbing experiments are too complicated to set up, because there are many cutting teeth at the same time, and it is difficult to measure the fundamental parameters in the cutting process. So, a fly hobbing model was set up using the single tool with the same profile of the tool as a tool hob, see figure 1 on the milling machine. The cutting conditions were selected as the same with the cutting teeth having the heaviest load on the actual hobbing process, shown in table 1.

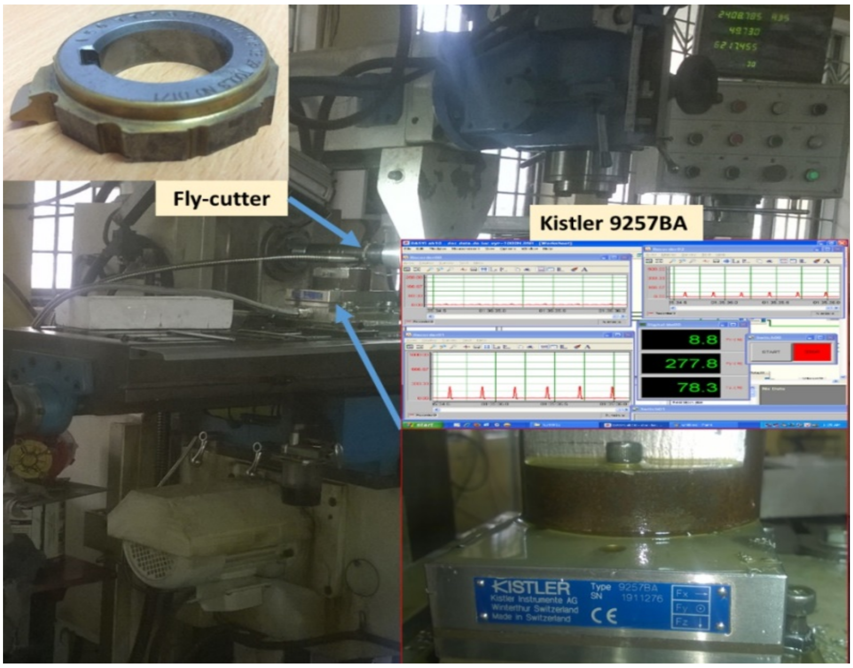

Figure 1: The Expérimental Setup.

Table 1: The Fundamental Parameters of the Real Hobbing Process and the Fly-Hobbing Process

Hooblng Process					Fly-Hobbing Process	
k	m	f	Lmax	Smax	t'	f'
1	1.75	1.27	12.92	0.108	2.75	0.259

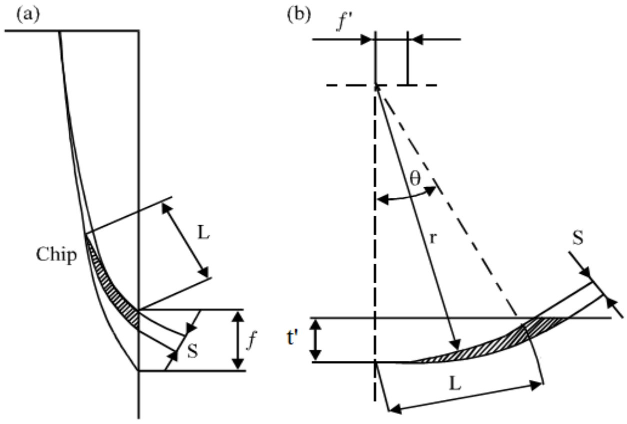

Figure 2: The Dimensions of the Chip in the Actual Hobbing Process (a) and the Fly Hobbing Process (b).

The fly hobbing process used the single tool the same with the profile tool of the hob tool, as figure 1. The fly cutting conditions are determined to ensure that the cutting mode for machining using a cutter on the horizontal milling machine is calculated to make the chip size equal to the maximum chip size of the hobbing process ($L=L_{max}$ and $S=S_{max}$), shown in figure 2. The maximum length and thickness of chips in the hobbing process are calculated by the Hoffmeiter's equation (1), (2) and shown in table 1 [8].

$$S_{max} = 4{,}9.m_n.Z_f^{(0{,}00925.\beta-0{,}542)}.e^{(-0{,}015.\beta)}$$
$$e^{(-0{,}015.x_p)}.\left(\frac{d_0}{2.m_n}\right)^{(-0{,}00825.\beta-0{,}225)}.\left(\frac{N}{k}\right)^{-0{,}877}$$
$$\left(\frac{f}{m_n}\right)^{0{,}511}.\left(\frac{t}{m_n}\right)^{0{,}319} \tag{1}$$

$$L_{max} = 3{,}081.m_n..e^{(-0{,}032.\beta)}.\left(\frac{d_0}{2.m_n}\right)^{(0{,}336)}$$
$$\left(\frac{N}{k}\right)^{-0{,}036}.\left(\frac{f}{m_n}\right)^{(-0{,}000425\beta^2+0{,}026.\beta+0{,}04)}$$
$$\left(\frac{t}{m_n}\right)^{0{,}0262} \tag{2}$$

The cutting depth and the feed rate of the fly cutting process are calculated by equation (3), (4) and shown in table 1.

$$t' = \frac{d_o}{2}.(1-cos\vartheta) \tag{3}$$

$$f' = \frac{S}{sin\theta} \tag{4}$$

Where: $\theta = \frac{2.L}{d_o}$

The work piece made of SCM420 steel and the single tool made from the hob of DTR were used in the this experiment, shown in figure 3. The KISTLER dynamometer set up on the horizontal milling machine and connected with the computer allowed to measure the cutting forces. In this research, The friction coefficient (μ) is calculated by equation (5) and shown in table 2.

$$\mu = \frac{F}{N} = tan\left(\theta - arctan\left(\frac{F_Z}{F_y}\right)\right) \tag{5}$$

Also, The cutting power has been determined following the measured cutting force. The cutting power can be determined from equation (6), respectively:

$$P_c = F_c . V \tag{6}$$

Where: F_C=N with $\alpha=0^0$

$$N = \sqrt{F_y^2 + F_z^2} . cos\left(\theta - arctan\left(\frac{F_z}{F_y}\right)\right)$$

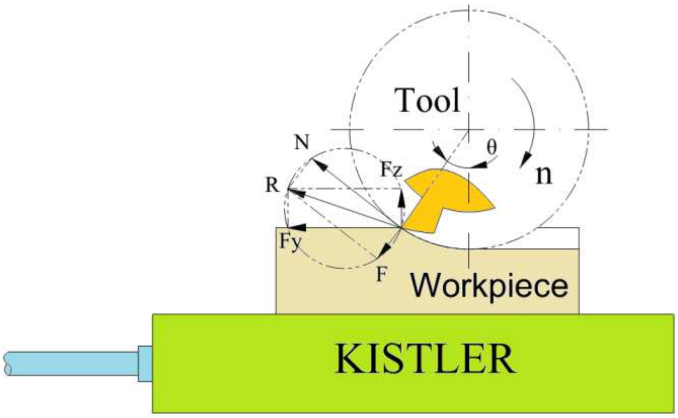

Figure 3: Measuring the Cutting Force in the Fly Hobbing Process.

2.2 Experimental Methods

Depending on the production system of FUTU1 Company in VietNam, the industrial lubricant was widely used to the machining processes due to its cheap cost. The study uses the Al_2O_3 nanoparticles of US Research Nanomaterials. The Al_2O_3 nanoparticle has many good advantages and spherical structure that could be made the Al_2O_3 nanoparticle improve the cooling and lubricating process during machining. Nanolubricants are made by mixing the normal oil with nanoparticles having the weight ratio of 0.1% ÷ 0.5% [5]. To analyze the effect of cutting speed (A), the nanoparticles size (B) and nanoparticles concentration (C) on the friction coefficient and cutting power, Al_2O_3 nano powders with the size of 20 nm, 80 nm and 135 nm was selected according to the economical requirement. The mixing ratio is 0.1%, 0.3% and 0.5%. The cutting speed with 38 m/min and 50 m/min was selected.

With the purpose of applying the nano cutting fluid for the hobbing process in the FUTU1 Company at Viet Nam, this study focused research the effects of some parameters on The friction coefficience and the cutting power in the fly-hobbing process. Hence, an experimental Taguchi Design is chosen for the fly-hobbing process as very simple and decreasing the number of experiments. In this study, the cutting speeds were selected based on the real machining process

in FUTU1, the Al_2O_3 nanoparticle sizes and concentrations were selected following the published reports. The effect parameters and interaction between them that were estimated by using the Taguchi analysis method. The signal to noise ratio (S/N) is used to analyze the effect of the input parameters on the output parameter. Higher values of the S/N ratio identify control factor settings that minimize the effects of the noise factors [9]. The friction coefficient and the cutting power are also studied with the "Smaller is better" feature. And The S/N ratio as determined as follows Roy R (1990) with the "Smaller is better" feature [9]:

$$S/N = -10 \, \text{Log}10 \, [MSD]$$

$$MSD = \sum_{i=1}^{n} y_i^2$$

3. RESULTS AND DISCUSSIONS

3.1 Experimental Results

The friction coefficient and the cutting power are calculated from the measured cutting force Fy and Fz, determined by the Kistler 9257BA in the during the experiment. The experimental results are analyzed by the Minitab 16 and shown in the table 2.

Table 2: The S/N Ratio Values for Input Parameters

No	A	B	C	Fy (N)	Fz (N)	µ	S/N (µ)	P(Kw)	S/N (P)
1	38	20	0.1	277.8	78.3	0.157213	16.07025	10.83449	-20.6962
2	38	20	0.3	232.6	73.6	0.124855	18.07191	9.199434	-19.2752
3	38	20	0.5	190.8	61.7	0.118454	18.52898	7.567235	-17.5787
4	38	80	0.1	282.9	77.3	0.165421	15.6282	10.99484	-20.8238
5	38	80	0.3	255.2	72.1	0.156581	16.10524	9.955912	-19.9616
6	38	80	0.5	235.6	70.1	0.142421	16.9285	9.247464	-19.3205
7	38	135	0.1	293.3	82.2	0.158731	15.98676	11.43168	-21.1622
8	38	135	0.3	282.8	80.8	0.153557	16.2746	11.04707	-20.8649
9	38	135	0.5	260.1	74	0.154701	16.21013	10.15516	-20.1337
10	50	20	0.1	282.4	75.2	0.172086	15.28508	14.40033	-23.1675
11	50	20	0.3	246.3	72.3	0.146171	16.70279	12.69955	-22.0758
12	50	20	0.5	222	69.1	0.12963	17.74592	11.52904	-21.2359
13	50	80	0.1	296.2	78.3	0.173953	15.19135	15.09186	-23.5749
14	50	80	0.3	262.8	74.1	0.157112	16.07581	13.48706	-22.5983
15	50	80	0.5	242.9	70.9	0.147728	16.61075	12.51616	-21.9494
16	50	135	0.1	295	84.6	0.152549	16.33179	15.16901	-23.6191
17	50	135	0.3	283	80.8	0.153748	16.2638	14.5446	-23.254
18	50	135	0.5	263.5	76.2	0.150278	16.46208	13.56271	-22.6469

3.2 Analysis ANOVA

The level effect of survey parameter to the friction coefficient in the fly-hobbing process was analyzed by using ANOVA analysis in MINITAB 16 with 95.2 % confidence intervals as shown in Table 3. ANOVA analysis indicates that the nanoparticle concentration (F = 71.03), nanoparticle size (F = 37.04), cutting speed (F = 12.99), the interaction between nanoparticle concentration and nanoparticle size (F = 17.05) were the greatest effect factors to the friction coefficient. Also, The level effect of survey parameter the cutting power to fly-hobbing process was analyzed with 96% confidence intervals as shown in table 4.

The result indicated that the nanoparticle concentration (F = 151.91), nanoparticle size (F = 79.94) and cutting speed (F = 1205.98) were the greatest effect factors to the cutting power. And, the interactions between the output factors

weakly effect on the cutting power in the fly-hobbing process. Figure 4 shows the influence of the cutting speed on the cutting power and the friction coefficient in the fly-hobbing process using the cutting fluid added Al_2O_3 nanopowders. The cutting power and the friction ratio increase together when the cutting speed increase from 38 (m/min) to 50 (m/ph). However, the friction coefficient increases more slowly than the cutting power.

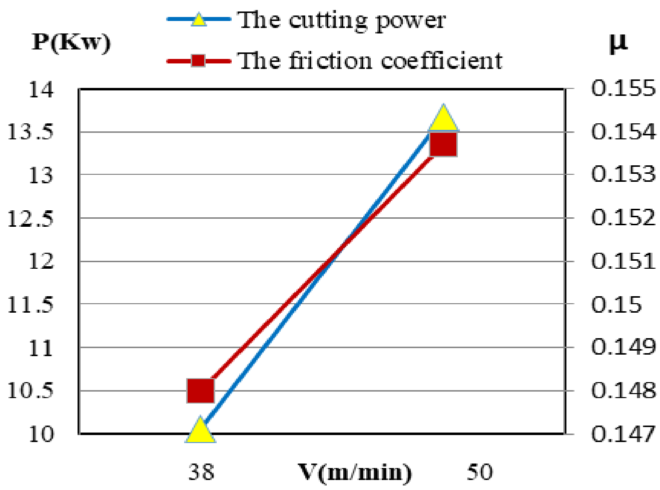

Figure 4: The Effect of Cutting Speed to the Friction Coefficient and Cutting Power in the Fly Hobbing Process.

Figure 5 shows the influence of the sizes of Al_2O_3 nanoparticle on the cutting power and the friction coefficient in the fly hobbing process. The result indicated that the cutting power decreases when the nanoparticle size decreases from 135 (nm) to 20 (nm). However, the friction ratio increases when the nanoparticle size decreases from 135 (nm) to 80 (nm), and decreases when the nanoparticle size decreases from 80 (nm) to 20 (nm). So decreasing the size of the nanoparticles mixed with the cooling lubricant can reduce friction, thereby reducing the required cutting power.

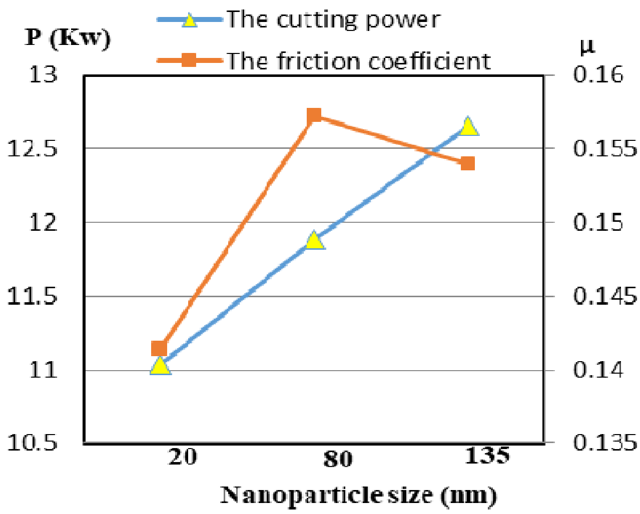

Figure 5: The Effect of Nanoparticle Size to the Friction Coefficient and the Cutting Power in the Fly Hobbing Process.

Figure 6 shows the influence of the concentrations of Al_2O_3 nanoparticle on the cutting power and the friction coefficient in the fly-hobbing process. When the nanoparticle concentration increases from 0.1 (%) to 0.5 (%), the cutting power and the friction ratio decrease together. The result indicated that when the nanoparticle size decreases from 135 nm

to 20 nm, the influence levels of concentration on the friction ratio gradually increase. With the nanoparticle size 135 nm, the friction coefficient is almost constant when changing the nanoparticle concentration. With the nanoparticle size 20 nm, the friction coefficient reduces most when changing the nanoparticle concentration. Using the nanolubricant mixed 0.5% nanoparticle 20 nm can reduce 25% friction ratio compared to using the nanolubricant mixed 0.1% nanoparticle 20 nm in the fly-hobbing process. When the nanoparticle concentration increases from 0.1 (%) to 0.5 (%), the cutting power and the friction ratio decrease together. Figure 7 shows the effect of interaction between nanoparticle size and concentration to the friction coefficient in the fly hobbing process. The result indicated that when the nanoparticle size decreases from 135 nm to 20 nm, the influence levels of concentration on the friction ratio gradually increase. With the nanoparticle size 135 nm, the friction coefficient is almost constant when changing the nanoparticle concentration. With the nanoparticle size 20 nm, the friction coefficient reduces most when changing the nanoparticle concentration. Using the nanolubricant mixed 0.5% nanoparticle 20 nm can reduce 25% friction ratio compared to using the nanolubricant mixed 0.1% nanoparticle 20 nm in the fly-hobbing process.

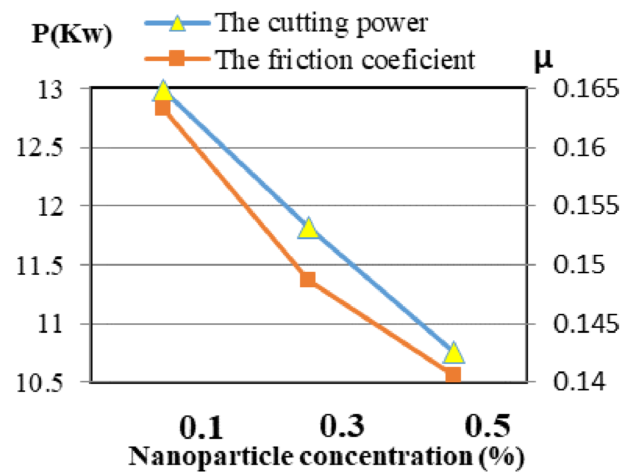

Figure 6: The Effect of Nanoparticle Concentrations to the Friction Coefficient and the Cutting Power in the Fly Hobbing Process.

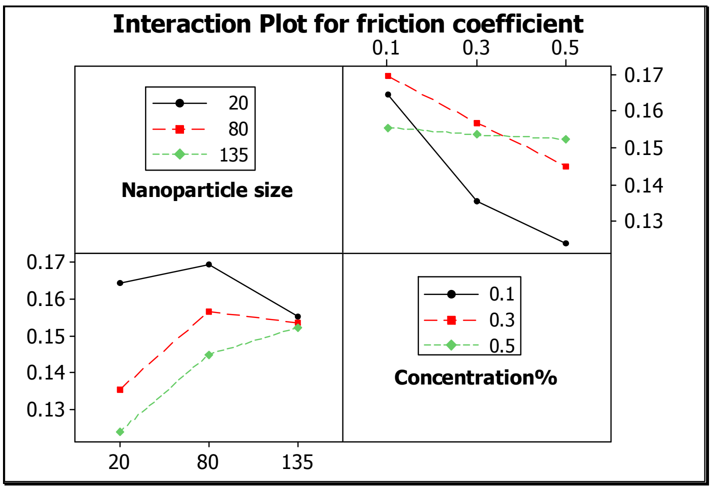

Figure 7: The Effect of Interaction between Nanoparticle Size and Concentration to the Friction Coefficient in the Fly Hobbing Process.

Table 3: The Level Effect of Survey Parameter to the Friction Coefficient in Fly-Hobbing Process

Source	DF	Seq SS	Adj SS	F-Values
A	1	0.000146	0.000146	12.99
B	2	0.000835	0.000835	37.04
C	2	0.001601	0.001601	71.03
A*B	2	0.00028	0.00028	12.43
A*C	2	0.000008	0.000008	0.37
B*C	4	0.000769	0.000769	17.05
Residual Error	4	0.000045	0.000045	-
Total	**17**	**0.003684**	**-**	**-**

Table 4: The Level Effect of Survey Parameter the Cutting Power in Fly-Hobbing Process

Source	DF	Seq SS	Adj SS	F-Values
A	1	58.9229	58.9229	1205.48
B	2	7.8143	7.8143	79.94
C	2	14.8507	14.8507	151.91
A*B	2	0.0128	0.0128	0.13
A*C	2	0.0751	0.0751	0.77
B*C	4	1.4832	1.4832	7.59
Residual Error	4	0.1955	0.1955	-
Total	**17**	**83.3545**	**-**	**-**

3.3 S/N Response Analysis

The effects of cutting conditions on the friction coefficient and the cutting power were analyzed using the Taguchi method. In Taguchi method, the S/N ratio is used to determine the optimal parameter settings. The Signal to Noise (S/N) ratio is calculated by Minitab 16 software and shown in Figure 8, 9 and Figure 10. Higher values of the S/N ratio identify control factor settings that minimize the effects of the noise factors. The results indicated that the lower cutting speed (38 mpm), the nanoparticle size 20 nm and the nanoparticle concentration of 0.5% contributed to the largest S/N ratio of the cutting power and the friction coefficient. The optimal parameters for the friction coefficient and cutting power are determined as cutting speed 38 (m/min), nanoparticle size 20nm and the nanoparticle concentration 0,5%. The figure 11 proved the interacted effect between the nanoparticle size and concentration on the S/N ratio for cutting power. These results evince that the interaction of the nanoparticle size 20nm and the nanoparticle concentration 0.5% are the interactions, which have the most effect on the largest S/N ratio.

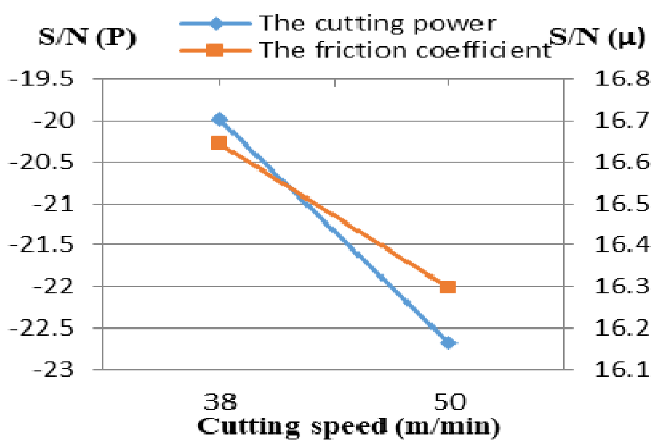

Figure 8: The Effect of Cutting Speed to the S/N Ratio of the Friction Coefficient and the Cutting Power in the Fly Hobbing Process.

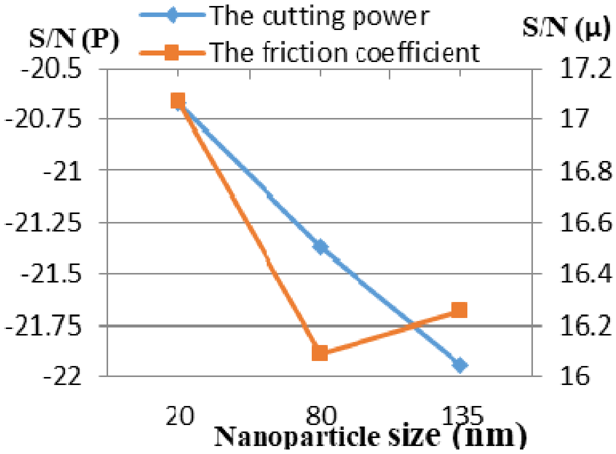

Figure 9: The Effect of Cutting Speed to the S/N Ratio of the Friction Coefficient and the Cutting Power in the Fly Hobbing Process.

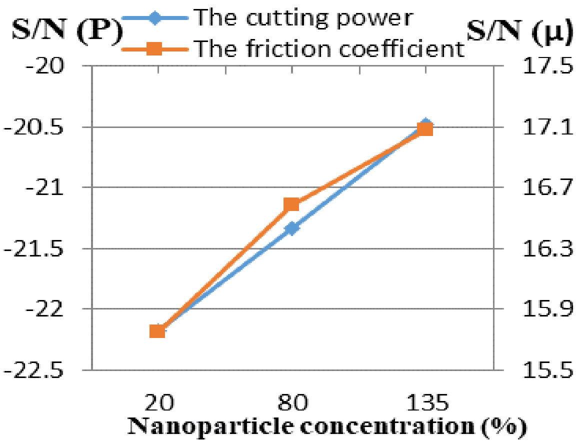

Figure 10: The Effect of Cutting Speed to The S/N Ratio of the Friction Coefficient and the Cutting Power in the Fly Hobbing Process.

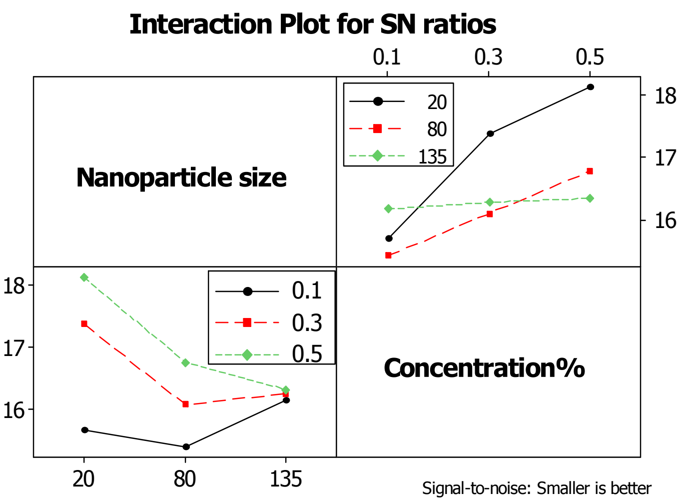

Figure 11: The Effect of Interaction between Nanoparticle Size and Concentration to the S/N Ratio Friction Coefficient in the Fly Hobbing Process.

4. CONCLUSIONS

Research has shown that nano fluid added Al_2O_3 nanoparticle into the cutting fluid in the fly cutting process, has reduced the friction coefficient and the cutting power while increasing the concentration and decreasing the nanoparticle size. In this research, optimizing the friction ratio and cutting power is obtained by applying the Taguchi method to determine the most effective factors. Based on the experimental and statistical results, the cutting speed, nanoparticle size, nanoparticle concentration and the interaction between nanoparticle size and nanoparticle concentration were the main factors that influenced the cutting speed. Aluminum nanoparticle mixed with the cutting fluid decreased the friction ratio and cutting power and obtained the smallest value with the nanoparticle concentration of 0.5%, the Al_2O_3 size 20 nm and the cutting speed 50m/min. Thus, nanofluid using dispersions of nano aluminum oxide (Al_2O_3) in normal oil may be applied for the gear hobbing process in FUTU 1. However, further research is needed on the temperature, tool wear in the fly cutting process and also the gear hobbing process.

5. ACKNOWLEDGEMENTS

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